

Development of Satellite Based Sensor for Improved Measurement and Validation of Ionospheric Parameters

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Award # N00014-98-C-0255

LONG-TERM GOALS

Having ionospheric electron density distributions as a function of height, latitude, longitude and time under different conditions is essential for scientific, technical and operational purposes. A satellite-based, swept-frequency, HF sounder can obtain electron density profiles on a global scale. We are developing a new-generation HF sounder that employs recent developments in technology, electronics and processing capabilities. It will provide global-scale electron density distributions, contours of fixed densities, maps of f0F2, hmax etc. It will allow us to map irregularities, estimation anomalous propagation and conditions for ducting, determine angles of arrival, etc. It will also be able to perform various plasma diagnostics and because of new flexibility, will be programmable from the ground to perform a variety of experiments in space. Need for such a system exists throughout the DoD and several civilian agencies. The specifications and relevant data for such a system are given in the table below:

New-Generation Topside Sounder	
Frequency Range	1-30 MHz
Antenna	Crossed Dipoles (Transmitter) Four short dipoles (Receiver)
Transmit Power	10 to 200 Watts
Pulse Width	30-100 microsecs. (coded)
Sweep Speed	Variable (typical MHz/sec.)
Frame Time	Variable (typical 30 secs.)
Receiver	Software controlled
Receiver Dynamic Range	100 to 120 dB
Orbit	1500 to 2000 KM.
Inclination	65 degrees (to include HAARP) 45 degrees (for mid-latitude)
Data Storage	On-orbit Processing

Some of the novel features of the system include:

1. Software based design.
2. Direction of Arrival information
3. SAR type processing capabilities
4. Reconfiguration and Flexible Architecture with multi mission capabilities
5. Artificial Intelligence and on-board processing.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Development of Satellite Based Sensor for Improved Measurement and Validation of Ionospheric Parameters				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dr. Suman Ganguly, 11350 Random Hills Road Suite 710, Fairfax, VA, 22030				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

OBJECTIVES

The overall objective of this STTR is to develop a suite of sensors for intercomparison, validation, and monitoring of the ionosphere. During Phase I, we have identified scientific, technical, and operational needs. Based on these, we have concentrated on the design and development of a state-of-the-art topside sounder and two radio beacons for deployment in a small, inexpensive satellite that can be quickly designed, constructed, and launched. We defined system requirements, performed initial system design, and demonstrated real-time analysis capabilities. We also explored some of the mission elements, e.g., satellite bus, launch vehicle, and ground station.

During Phase II, the objective is to perform a complete system and engineering design compatible with mission elements. For this, we will perform laboratory-based design and development of critical subsystems, demonstrate their capabilities and, finally, perform a systems integration and engineering design compatible with the chosen satellite and launch system.

During Phase III, a spaceworthy system will be developed, integrated, and deployed.

APPROACH

Several elements of the proposed topside sounder are novel, e.g., the software control, the on-board data processing, and the SAR mode. Some of the critical subsystems include:

- Sounder Hardware
 - A DSP-based, software-controlled sounder with a coded waveform for improved performance at low power will be developed and a laboratory prototype built. It will be based on multiple Analog Devices AD2106X DSP processors. It will also include a complete Tx-Rx control unit.
 - This sounder control unit will be integrated with HF transmitter and receiver modules, both of which will be developed and laboratory prototypes built.
 - The antenna system will be designed using the Numerical Electromagnetic Code (NEC) code and a laboratory prototype built. It will be able to transmit between 1 and 30 MHz. For reception, it will obtain the signals needed to determine angle of arrival. Antenna matching will be performed dynamically.
 - The complete set of prototypes will be tested as a ground-based ionosonde.
- Sounder Software
 - The expert system and data-analysis techniques demonstrated during Phase I will be refined.
 - The direction-finding algorithm will be developed.
 - The synthetic-aperture algorithm will be developed and tested on synthetic data.
 - Control sequences for the sounder will be developed.

- This software will be tested on the ground-based prototype sounder and the data acquired with it. The synthetic-aperture algorithm will be tested on synthetic data.
- System Integration Plan and Engineering Design for the Mission Elements
 - **Satellite System:** other sensors, payload mass, power requirements, thermal requirements, pointing control and knowledge, on-board data reduction and compression, data storage, telemetry, command handling, interaction among sensors, redundancy, and environmental issues. Much of this will be determined by the selection of the appropriate satellite bus, e.g., buses made by Spectrum Astro, OSC, and Ball Aerospace.
 - **Launch System:** launch vehicle, launch site, and certification. This will be affected by the payload, satellite bus, and desired orbit. Possibilities include Pagasus and Taurus, but consideration will not be limited to these.
 - **Ground Segments:** S-band versus X-band telemetry; one versus multiple ground stations; command structure and control; cross-links; data reduction, visualization, and archiving; and data distribution to end users.
 - **Operational Plan:** agencies, experimental priorities, experimental plans.

WORK COMPLETED

The contract started on 06-08-98, and a subcontract to Utah State University has been formalized. Initial design of the sounder is currently being performed. Utah State will be primarily responsible for space based antenna related issues and integration with the satellite system.

One of the novelty of the proposed approach is the software based architecture. Various software modules are currently being generated.

RESULTS

The design effort is progressing smoothly. A conference abstract for Ionospheric Effects Symposium (IES 99) has been submitted.

IMPACT/APPLICATIONS

The proposed topside sounder will provide, as its primary measurement, the electron density distribution throughout most of the ionosphere, over most of the world and under various solar and geophysical conditions. In its secondary measurement mode, the synthetic aperture radar (SAR) mode, the sounder will provide a precise mapping of ionospheric irregularities. These observations will help us to:

- Provide electron densities and temperatures with which to validate numerous theoretical models of the ionosphere and to contribute to empirical models of the ionosphere.
- Validate the density distributions derived from indirect techniques such as model inversion of satellite EUV measurements, tomographic inversion of total-electron content (TEC) or integrated column densities from ground-based observations of satellite beacons, etc.

- Provide inputs for assimilative ionospheric forecast models.
- Improve performance of GPS systems because of measured plasmaspheric TEC.
- Provide global mapping of ionospheric parameters, including electron densities and electron temperatures and, hence, plasma scale heights, for scientific research and operational systems.
- Allow monitoring of seismo-ionospheric events for earthquakes, nuclear explosions, etc.
- Provide precise mapping of irregularities, tilts, and ionospheric anomalies, etc., thereby facilitating the understanding and prediction of scintillations and of other satellite communication issues.
- Provide superior understanding of anomalous radio propagation through ducting, z-mode, around-the-world propagation, sporadic E, and scatter propagation.
- Measure various plasma resonances near the spacecraft, provide precise measurements of magnetic fields, and diagnose the response of the topside ionosphere to HF modification experiments.
- Provide a HF test-bed in the ionosphere that could be used to perform various sophisticated experiments.
- Test technology that could be applied in diverse areas of communications, radar, space exploration, and related areas.

TRANSITIONS

Direct observations of ionospheric features are crucial for various operations in communications, navigation, early warning, radar, etc. And will be especially invaluable for agencies like the Navy, Air Force, Army, NSA, CIA, DISA, and NOAA. The data will be of immense help to ionospheric scientists, radio and communications engineers, ionospheric modelers, radio amateurs, and the space-weather community. Ionospheric information and predictions made with the help of these data will be useful to GPS users, radio users, satellite users, and electric utilities, as well. The data obtained with this system could be sold through insurance providers for satellite systems, electric utility providers, space weather analysts, radio communication and radio users, etc. A network of six such topside sounders would provide complete coverage for operational systems. Alternatively, the ionospheric data from one such topside sounder and from other sources could be assimilated into a new generation of physical models to provide global ionospheric predictions.

RELATED PROJECTS

The Center for Remote Sensing (CRS) is an R&D organization with strong ties to various universities and research laboratories throughout the world. The scientists and engineers at CRS have international reputations: CRS has completed or is working on more than 40 contracts for various agencies of the U.S. government during the past 12 years. Some of the relevant projects include:

- Digital Wideband Electromagnetic Sensors (DAAH01-98-C-R135)
- High Data Rate HF Communication (MDA972-97-C-0005)
- Improvements in HF Propagation using GPS (N00039-95-C-0024)
- Active Calibrator for TRMM Radar (NAS5-38010)

- Intelligent Receiver (NAS5-31928)
- Improved Propagation based on Physical Ionospheric Model (DAAB07-91-C-B014)
- Modeling of Radomes Shielding Spiral Antennas (N60530-91-C-0105)
- Design of Helical Antenna (DAAH01-90-C-0562)
- Active Space Plasma Physics Program (NAS5-31195)
- Improved Antenna for SAR Calibrator (NAS7-1084)
- Pulse Propagation Model (F29601-86-C-0248)
- Scintillation and clutter in space-based radar design (DAAH01-86-C-0248)
- Improvements in HF Broadcasting for Voice of America (N000173-86-M-7659)
- Incoherent-Scatter Studies (NSF)

Utah State University (USU), with which CSR is teaming, has a strong background in ionospheric and atmospheric research through its Center for Atmospheric and Space Sciences (CASS) and extensive experience in building space instruments and spacecraft through its Space Dynamics Laboratory (SDL). In addition to building and flying numerous rocket experiments and complete rocket payloads, orbiting space projects include a number of Shuttle payloads, such as: CIRRI-1A and major portions of the THETHER experiments; experiments for major spacecraft such as the SPIRIT III, the primary sensor aboard the MSX spacecraft, the SABER experiment for TIMED, and the prime IR detection system for WIRE, a SMEX project; several spacecraft, including, the collaborative American-Russian SKIPPER and RAMOS spacecraft. These latter two involve USU's use of small satellite buses, similar to the ones being considered here, and its executing the full integration of the spacecraft. A feasibility study is just being completed for NASA/LeRC on the possible spacecraft and launch vehicles needed to fly HOSS. In addition to the same small commercial satellite buses, due consideration was also given to USU's fabricating the whole spacecraft. Under some conditions, this can be very cost effective. Thus Utah State University has the contacts and databases to properly select the satellite bus and the launch vehicle, it also has the experience to build the space-qualified payload and to integrate it with the satellite bus. Alternatively, it can both build and integrate the bus and payload.